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Experimental observation of symmetry protected bound state in the radiation continuum in the periodic array of ceramic disks

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Abstract. We observe experimentally symmetry protected bound states in the continuum (BICs) in the stack of ceramic disks. We analyze transformation of the resonant state into BIC with increasing of the number of disks theoretically and experimentally. In the experiment we measure the transmission spectra through the array of ceramic disks at GHz frequencies. We observe a quadratic growth of the Q-factor of quasi-BIC with the number of disks due to material losses. We cross-check the observation of BIC in the transmission spectra by measurement of the field profiles which are a good agreement with the results of the numerical simulations.

1. Introduction
It is well known that a dielectric rod or slab supports waveguide modes formed under the condition of total internal reflection from the waveguide boundaries. The wavenumber of the waveguide modes lies under the light line of the surrounding space making them orthogonal to the radiation continuum[1]. The spectrum of the leaky modes lies above the light line. However recently it was acknowledged that introduction of periodic modulation of the refractive index along the rod's axis discretisize the radiation continuum, that could result in enormous supress of leakage. With a certain set of parameters the leakage is completely blocked and the resonant state is localized, i.e. decoupled from the radiation continuum. Such localized solutions are known as bound states in the continuum (BICs) [2, 3]. Our goal was to reseach possibility of recreating resonant state in the finite rod array with simular features.

2. Transmission spectra and scattering cross section measurements
Resonant state can be exited by simple wave and Q-factor can be obtained by measurment of total cross section. But this method have one major flaw.

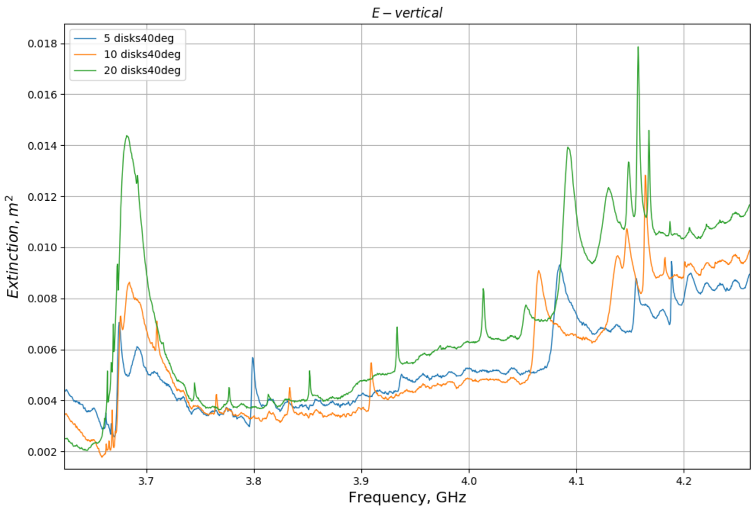

Figure 1. Measured extinction for 5, 10 an 20 disks chain

Fig. 3 shows total cross section for 5, 10 an 20 disks chain. It is nearly impossible to distinguish one peak and measure Q-factor. As shown on Fig. 4, modes with $m = 0$ and $m = 2$ become mixed with each other, when we increase amount of disks. This problem solved by usage of loop antennas, because it can exite only modes with $m = 0$

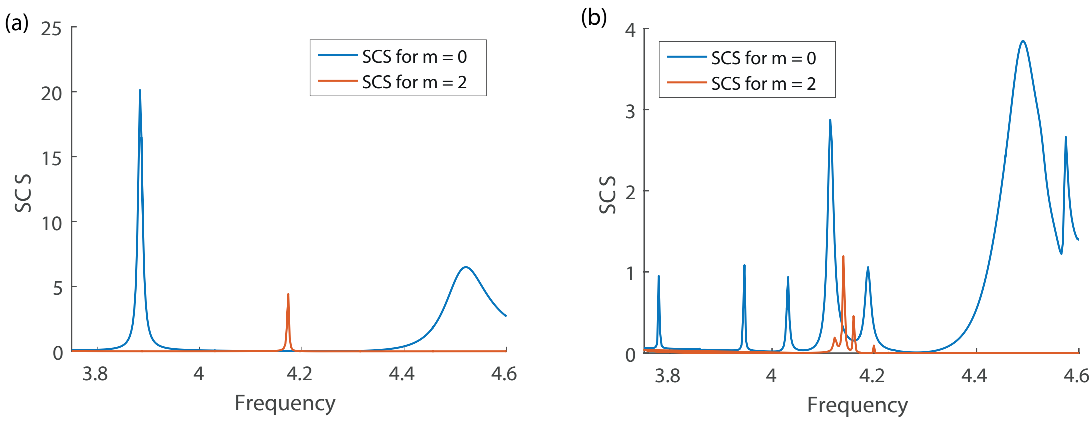

Figure 2. (a) Theoretical SCS for one disk (b) Theoretical SCS for ten disks

The fabricated prototype is shown in Fig. 3. The disks are fabricated from BaO-TiO_2 microwave ceramic with the permittivity of ε=40 and tan(δ)=0.0001 (measured at 1 MHz). The radius and the height of the disks are D=10.2 mm and h=10.1 mm, respectively.

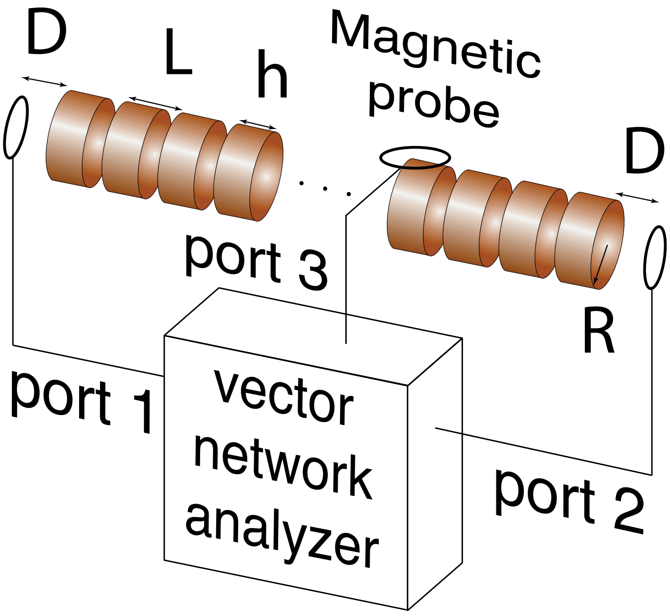

Figure 3. Experimental setup for transmission spectra and field profile measurment

We characterize the resonances of the chain by measurement its transmission with two loop antennas connected to the vector network analyzer. The results of the measurements are shown in Fig. 4. One can see that the spectrum consists of two bands. The dashed line divides the spectrum on waveguide modes and resonant states in the continuum. Fig. 4 (b) shows the the transmission in the region of leaky resonances. The last peak in the series corresponds to the quasi-BIC.

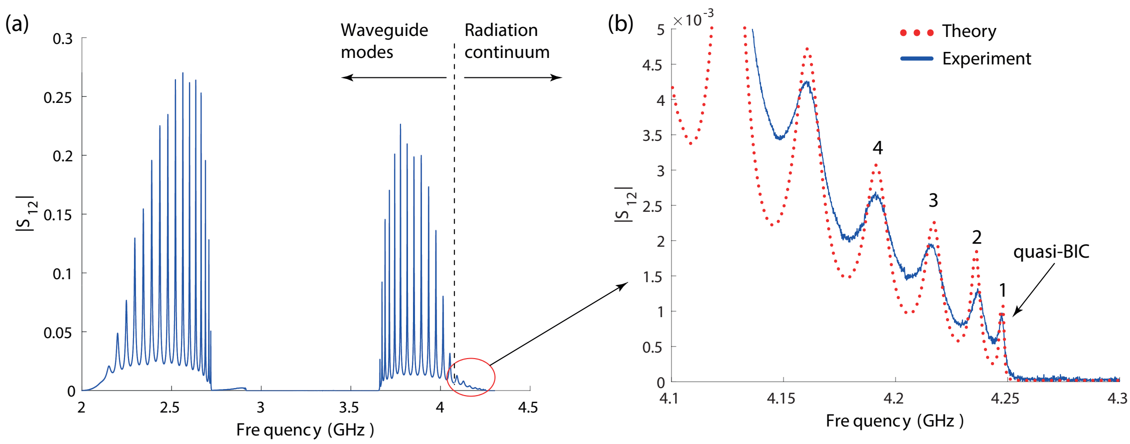

Figure 4. (a) The transmission spectra of the array of 20 disks between two loop antennas as sketched in Fig. 1. (b) The transmission spectra in the radiation continuum.

3. Results

The dependence of its Q-factor on the number of disks is shown in Fig. 5. (mode 1). In the absence of losses the Q-factor growth quadratically with N. However, in the experiment the Q-factor saturates because of the material losses in ceramics. Therefore, at low N the total losses are mainly determined by radiation leakage but at N of several tens absorption makes the main contribution.

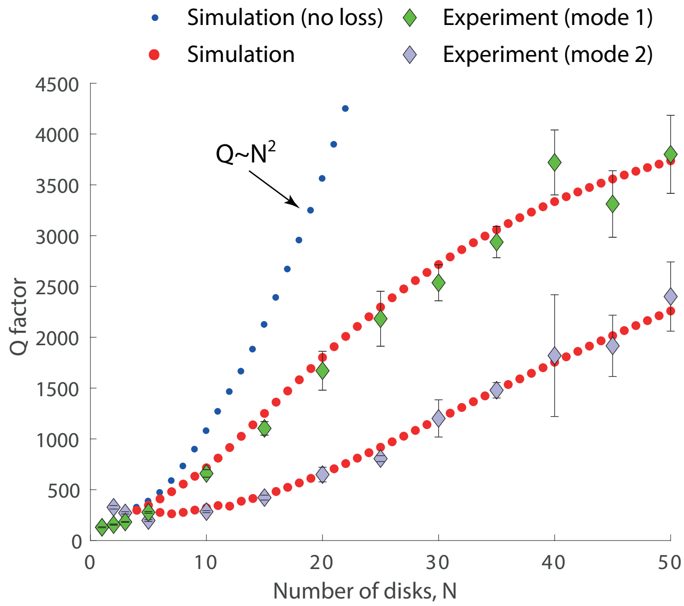

Figure 5. Comparison of experimental results and theoretical simulation for first 2 modes. Theoretical simulation made in COMSOL.

4. Conclusion

We experimentally analyzed the transformation of a resonant state into BIC with increase the number of the disks in one dimensional chain of scatterers for the first time. The obtained results are very important for practical implementation of BIC in radiofrequency and photonic devices.

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